Alloy Undercooling Experiments in a Microgravity Environment: Recent Results from the STS-83 and STS-94 Missions

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Objectives

The focus of this program is to study of the effect of microgravity on metastable solidification. By observing changes in the mechanism for nucleation of the stable phase following primary recalescence from undercooled melts, the role of convection in phase selection may be evaluated.

Microgravity

Undercooling in containerless processing has shown promise in producing metastable phases and materials that exhibit improved chemical homogeneity and ultra-fine grain sizes. One aim of this research is to develop an understanding of the role of convection in the metastable to stable transition that has been observed in multi-component systems, notably in the Fe-Ni and Fe-Cr-Ni alloys. The mechanism for nucleation of the second phase and the delay time observed in this transformation appear to be dependent on solid movement and coalescence, probably the result of convective flow. Ground-based experiments require maintaining a balance between the levitation force and gravity, while space experiments need far less energy to position the sample. With a reduction in melt convection, we have investigated the apparent changes in phase selection for these two different environments. Microgravity is thus an integral requirement for the successful attainment of the goals of this program.

Ground-Based Results

The rapid solidification of two ternary steel alloys, a Fe-12wt%Cr-16wt%Ni alloy and a Fe-16wt%-12wt%Ni alloy, were investigated under containerless processing conditions using the MIT electromagnetic levitation facility. A high-speed digital video technique was used to image growth into the undercooled melt for both the metastable ferritic phase and the stable austenitic phase. At a given liquid temperature, the velocity of the fcc gamma phase is greater than the bcc delta phase. Above a critical undercooling, the metastable phase nucleates first and, after a delay, a second thermal rise is observed during transformation to the stable phase. Double recalescence events were observed at temperatures consistent with the $T_{\rm o}$ temperature of the bcc phase defining a value of the critical undercooling for metastable nucleation which is significantly lower than previously predicted.

The velocity for growth of the stable phase into the semi-solid which forms during primary metastable recalescence was also measured and found to be independent of the initial undercooling. During simultaneous growth at temperatures below the undercooling where the velocities of the two phases are equal, the metastable phase grows into the liquid faster than the stable phase grows within the semi-solid and thus a distinct double recalescence event is observed. Above this

temperature, the equilibrium phase can overwhelm the slower metastable phase and break into the undercooled liquid. Such a double recalescence event can therefore appear as a single event. Since the delay time is a weak function of temperature, a model based on competitive growth of the two phases successfully predicts the limit where double recalescence events may be detected as a function of sensor geometry.

Flight Results

Molten samples of the ternary steel alloys were successfully processed in a containerless fashion using the TEMPUS electromagnetic levitation facility aboard the Space Shuttle *Columbia*. The solidification rate was measured as a function of undercooling using a combination of video downlink and a perpendicular set of two high-speed pyrometers. Nucleation was induced within the field of view using a Zr-coated stimulation needle.

Using the growth competition model, we have defined a deviation parameter based on the ratio of the observed to predicted delay times. This parameter may then be used to compare the ground-based and space results. Using a null hypothesis – theorizing that ground and space results are samples taken from the same normally distributed population – we calculate the statistical confidence that this hypothesis is valid. Ground-based images during double recalescence show three types of mechanisms for nucleation of the second phase, two within the semi-solid and one at the interface between primary phase and liquid. Since the model can account for the first two mechanisms, we propose that a link exists between the reduced convection in space and the deactivation of the third of these mechanisms in microgravity.

Conclusions

We have successfully developed a model that combines:

- 1. simultaneous growth of competing phases;
- 2. the delay between recalescence events;
- 3. assumptions on the mechanism for secondary nucleation of the stable phase; and,
- 4. given a known relationship between the sensor and the nucleation events

to explain the role of growth competition in phase selection during rapid solidification of undercooled hypoeutectic Fe-Cr-Ni alloys. Using this model, we have demonstrated that a difference exists between the high convective environment of ground-based electromagnetic levitation and that attainable in microgravity.